INTERNATIONAL JOURNAL OF
ENERGY AND ENVIRONMENT
ISSUE ON APPLIED MECHANICS RESEARCH
Volume 8, Issue 4, 2017 pp.331-338
Journal homepage: www.IJEE.IEEFoundation.org

Enhancement of the mechanical properties for above-knee prosthetic socket by using the bamboo fiber

Jumaa Salman Chiad[1], Muhammad Safa al-Din Tahir[2]

[1] Al-Nahrain University, College of Engineering, Prosthesis and Orthotics Engineering Department, Baghdad, Iraq.
[2] Al-Nahrain University, College of Engineering, Mechanical Engineering Department, Baghdad, Iraq.

Received 27 Sep. 2016; Received in revised form 30 Oct. 2016; Accepted 30 Oct. 2016; Available online 1 July 2017

Abstract
Researchesspecialized in manufacturing of prostheses showed a major development in improving the mechanical and physical properties in the trend to get the best mechanical specifications, lighter in weight, lower cost and ease of manufacturing. For this purpose this research includes manufacture of above the knee prosthetic socket of lamination of four layers consisting of (1 bamboo 2 fiber carbon 1 bamboo) instead of lamination of ten layers which consist of (4 perlon 2 fiber carbon 4 perlon) which is most commonly used in the manufacture of prosthetic socket at the moment. Tensile test and fatigue test were conducted, as well as interference testing pressure between the residual limb of leg of the patient with socket by device F-Socket to use these pressures later as boundary condition in the simulation program ANSYS 14.5, which will simulate the distribution of Von-Mises stresses, values of deformation and the factor of safety for both available and proposed sockets. The results revealed an increase in the values of each of the yield stress and tensile stress Young's modulusand stress endurance by 20.1%, 162.7% 0.80% 0.241%, respectively, as the results of the prosthetic socket simulations manifested increase in safety factor from 0.998 to 3.85 and decrease in the highest amount of deformation from 10 mm to 5.5 mm.

Keywords: Prostheses, Socket, Bamboo, Carbon, Fatigue, Stress.

1. Introduction
The prosthesis for lower limbs is the most common way to compensate for the lost part for carrying out the activities of life as normal, such as walking, standing and even jogging. This prosthesis depends on the type of amputation which may be partial foot, ankle dislodgement, below knee, through the knee, above knee, hip disarticulation or hemipelvectomy [1]. This study will address socket prosthesis, which has a direct contact with the residual part of above the knee amputation. People with special needs who wear this type of prosthesis suffer from continuing failure of prosthetic socket. Different reasons are responsible for that they are related to the type of material used in manufacturing the socket or conditions of load exerted on the prosthetic socket. There are many designs and materials used at the moment for the manufacture of sockets prosthesis with meets the some extent mechanical specifications required but this specification may be unsuccessful when using this sockets by patient with big weights or with high activity.

M. J. jweeg et al [2] studied the mechanical properties of the above knee prosthetic socket in order to set up the basis of the mechanical properties of materials used (perlon with fiberglasses) for the manufacture of this type of the prosthetic sockets. The optimum mechanical and physical properties were reached when the laminations consisted of (3 perlon 2 fiberglasses 3 perlon).
S. J. Jana et al [3] studied and compared the mechanical properties of two types of through the knee prosthetic socket lamination (4 perlon +2 fiber carbon +4 perlon with 3 perlon +fiber carbon +3 perlon). The tensile and fatigue testes were done on these materials. The results show that the lamination (4 perlon +2 fiber carbon +4 perlon) ultimate stress, yield stress, modulus of elasticity and endurance limit increase compared with the other laminations by (18.7%, 30.7%, 64% and 180%) respectively.
H. C. Shireen et al [4] studied the mechanical properties and the effect of stress relaxation on the prosthetic socket for below the knee amputation where a tensile testing and testing of stress relaxation were conducted on several materials (4 perlon+ 4 fiberglass +4 N-glass, 4 perlon +2 N-glass + 4 perlon, 2 perlon + 2 fiberglass +2 perlon + 2 fiberglass, 4 perlon+2 fiberglass +4 N-glass and Polypropylene). It is concluded that the material which consists of (4 perlon+ 4 fiberglass +4 N-glass) has an optimum properties and a higher resistance to deformation resulting from decreasing the stress relaxation modulus than other composite materials and polypropylene.
M. J. Ibrahim [5] studied the hygrothermal effect on the mechanical properties and fatigue characteristics of prosthetic socket lamination. Six laminations composite materials were used in manufacturing prosthetic socket. The reinforced materials of these laminations were perlon, fiberglass, and Carbon nanopowder (CNP) while the matrix material was polyurethane resin.tensile and fatigue tests under the hygrothermal effect to find the mechanical properties and fatigue characteristics. The results show that the lamination (505+CNP) has higher modules of elasticity and stiffness reaching (2.22 Gpa and 2308 KN/m) respectively and has the highest endurance limit equals (18.45Mpa). This work suggests lamination (1 bamboo 2 fiber carbon 1 bamboo) compared with the best currently available lamination (4 Perlon 2 fiber carbon 4 perlon) for getting physical specifications and mechanical and fatigue characteristics of the best.

2. Bamboo fiber

The bamboo fiber is a type of renew fiber cellulose, which is assembled from raw materials of bamboo pulp refined from bamboo by the process of hydrolysis-alkalization and multi-phase whitening, then with treatment pulp, it is converted into bamboo fibers [6].
The bamboo fiber properties are [7]:

- Bamboo fiber is strong and has durability and tenacity.
- This yarn is softer compared with cotton, smoothness-like softness of cashmere and silk threads.
- Has high moisture absorption and ventilation property because there are many holes and gaps in this fiber,Therefore, clothing made from bamboo fiber has the ability to vaporize human sweating quickly.
- Low density because of the many gaps and holes.
- Bamboo fibers contain natural elements enabling them to be anti-ultraviolet and anti-bacterial so they are able for deodorizing.
- Bamboo yarn is characterized by large elasticity.
- Bamboo fiber is biodegradable so it is eco-friendly.

3. Experimental part

3.1 Manufacturing of above knee socket laminations

3.1.1 Materials of prosthetic socket

The following two materials were used to in manufacture prosthetic socket:

A. Available prosthetic socket material, the socket was made from these materials:

- Knit from perlon.
- Woven from fiber carbon.
- Laminations resin 80:20 polyurethane.
- Hardening powder.

B. Suggestion prosthetic socket material, The socket made from these materials:

- Knit from bamboo.
- Woven from fiber carbon.

- Laminations resin 80:20 polyurethane.
- Hardening powder

3.1.2 Used equipment to manufacture prosthetic socket

Gypsum mold: Mold is made of gypsum material with an external shape of parallelogram dimensions of 12 cm 12 cm 30 cm. This mold underwent operations sculpt and refine the surface because the inner surface of the material to be manufactured will take the form of the outer surface of the mold see Figure (1a). *Polyvinyl Alcohol PVA bag*: this bag is worn on the gypsum mold and takes its shape perfectly, characterized this bag is withstand high temperatures that are formed by reaction the laminations resin with hardening powder, the air between the bag and the mold Suction by vacuum device see Figure (1b). *Vacuum system*: it consist of pipes, valves, and vacuum pump used for this system to suction the air completely out of the two spaces, the first between the first bag and the mold Gypsum, and the second space between the two bags .the purpose of vacuum in the first space is to take the shape of gypsum mold perfectly and making sure there are no bubbles changing the external shape of the mold, the second space for suction air from the space in which the casting process occurs and ensures that are no bubbles in the cast, see Figure (1c).

3.1.3 Manufacturing procedure of prosthetic socket

- Make gypsum mold sculpt and refine as these dimensions 12cm 12cm 30cm as shown in Figure (2a)
- Put the first piece from the PVA on the gypsum molds as shown in Figure (2b) and suction the air between PVA and gypsum by the vacuum system.
- For available material put the first knit of perlon as shown in Figure (2c) whose density is 0.01331g/cm^2, as for suggested material putting the first Knit of bamboo yarn as shown in figure (2d) whose density is 0.0332 g/cm^2
- Putting the mat from carbon fiber whose direction is 0˚,90˚ as shown in Figure (2e) with density is 0.0269 g/cm^2
- For available material put the second knit of perlon as shown in Figure (2f) that density is 0.01331g/cm^2, as for suggested material putting the second knit of bamboo yarn as shown in Figure (2g) whose density is 0.0332 g/cm^2.
- Put the second piece from the PVA and suction the air between two bags is sucked by thevacuum system. Mix the laminations resin with hardening powder, put this mixture on these layers as distributed equally as shown in Figure (2h).

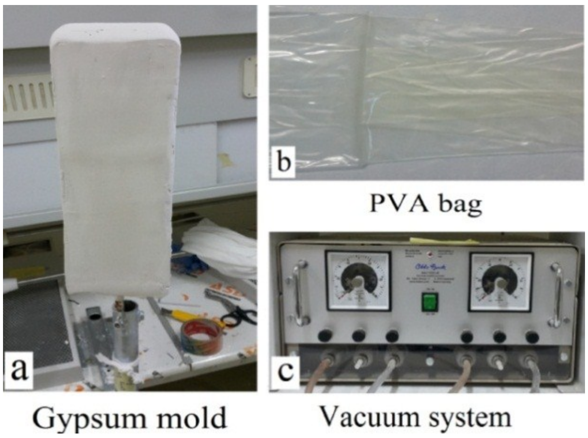

Figure 1. The Equipment used to make material prosthetic socket.

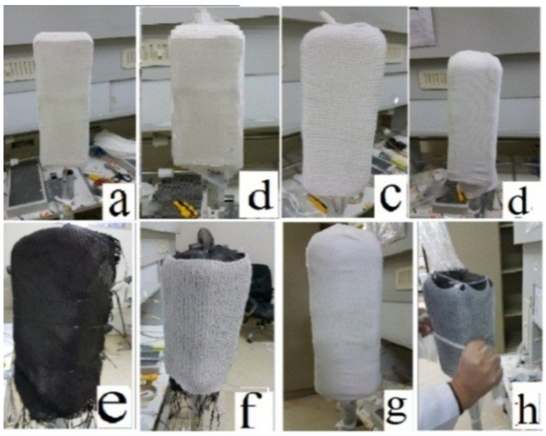

Figure 2. Procedure for made material of prosthetic socket.

3.2 Calculation of the physical properties of the laminated materials

In this part, it is important to know the physical characteristics and the components to improve the mechanical and physical properties in the future. The physical properties such as thickness, weight density, weight density per unit area, proportions of the components and volume fraction for each prosthesis socket materials were found by using a digital vernier and digital sensitive weighting device. The densities and volume fraction for all materials are calculated as follows:

$$\rho = \frac{m}{V} \tag{1}$$

$$\rho_{area}=\frac{m}{V}\times thickness \tag{2}$$

$$component\ ratio = Cr = \frac{V_{item}}{V_{total}} \times 100 \tag{3}$$

$$v_f = \frac{V_{fibers}}{V_{matrix}+V_{fibers}} \times 100 \tag{4}$$

3.3 Tensile test

This test was done at Al-Nahrain University in Mechanical Engineering Department by the material testing machine Testometricas shown in Figure 3. The specimens were cut with *computer numeric control* (CNC) machine and according to ASTM D638 type 4 [8] as shown in Figure 4. All specimens were tested at strain rate equals to 2 mm/min.

Figure 3. Material testing machine Testometric.

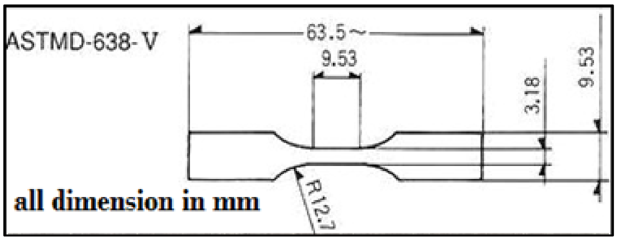

Figure 4. Tensile test specimens and the dimensions for available and suggested material.

3.4 Fatigue test

Fatigue is a form of failure that occurs in material when socket is subjected to dynamic and fluctuating stresses as a result of walking. The fatigue properties of the tested material can be described by scheme stress against a number of cycle curve (S-N curve), using fatigue machine (HSM20) shown in Figure 5. This machine applied the alternating bending stress at rotational speed 24 revolutions per second. The alternating bending fatigue specimens were manufacturing according to manual of the machine [9] as shown in Figure 6. All calculations (length and deflection of testing) were done according to the nomogram in manual of the machine.

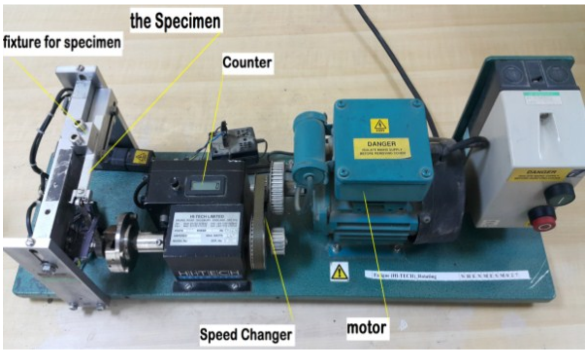

Figure 5. Fatigue machine (HSM20).

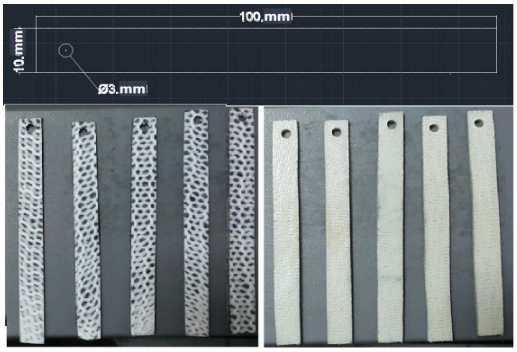

Figure 6. Fatigue test specimens and the dimensions for available and suggested material.

3.5 Measuring the interface pressure

The interface pressure between the residual limb and socket measured by using the F-Socket sensor as shown in Figure 7. Connect the sensor with a computer program (F-Scan) to obtain the image showing the distribution and values of the pressure subjected on the sensor. Put the sensor on four regions in the residual limb (front, back, side internal and external). The data extracted from this program to be useful in the simulation program ANSYS. This test dons in Department of Engineering of Prosthesis and Orthotics at the Al-Nahrain University. Data of the case study are listed in the Table 1.

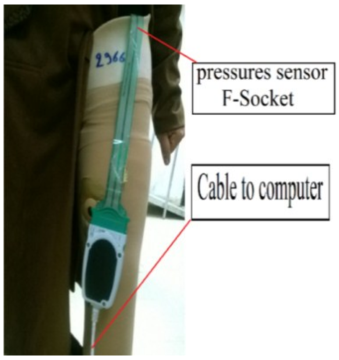

Figure 7. Position of pressure sensor at AK prostheses.

Table 1. Data of the patient who conducted examinations process.

Gender	female
Date of birth	1992/8/1
weight	49 kg
Length	155 cm
Type of imputation	AK
Side imputation	Lift leg

4. Numerical analysis for above knee prosthetic socket

The finite element method (FEM) is now extensively used in the multi purposes fields in engineeringand science, taking the advantage of the rapid development of digital computers with large memory capacity, as well as, fast computation. The method is recognized as one of the most powerful numerical methods because of its capabilities which include complex geometrical boundaries and non-linear material properties. In this work, FEM with the aid of ANSYS workbench 14.5 software was used as a numerical tool to illustrate the effect of the fatigue performance in a structure element to determine the behavior of stress distributions contour, total deformations, and areas of safety factor [10].

The general analysis by using ANSYS workbench version 14.5 has three distinct steps they are:

- Building the geometry as amodel.
- Applying the conditions of boundaries load and get the solutions.
- Reviewing theresults.

5. Result and discussion

5.1 Physical properties of manufactured materials

This part includes finding the physical properties (thickness, mass density, mass density per unit area and volume fraction) as listed in Table 2 and the proportions of the components for prosthetic socket materials (suggested and available) as inserted in Table 3. The physical properties of the suggested material are compared with available material noting increase in mass per unit area by 8.3%, the proportion of lamination resin between the suggested materials was comparing with available material noting the decrease by 3.2%.

5.2 Mechanical properties

The mechanical properties as (σ_y, σ_{ult} and E) of each tested material represent the average value for three attempts as listed in Table 4. These properties will be used later in the fatigue test, as well as these properties are the key data in the program ANSYS 14.5 to simulate the prosthetic socket and analyze stress and deformation and safety factor. From a table results of the mechanical properties the properties of suggested material were compared with the available material, noting increase in values of yield stress, ultimate stress and modulus of elasticity by 20.1%, 162.7% and 80 % respectively.

Table 2. Physical properties for manufactured materials.

Material	Available	Suggested
Thickness (mm)	3.7	3.7
Density (g/cm^3)	1.2	1.3
Mass per unit area (g/cm^2)	0.444	0.481
Volume fraction V_f	0.33	0.352

Table 3. The proportions of the components of manufactured materials.

The material	Available	Suggested
the proportions of the components	Perlon (24.5%) Fiber carbon (8.5 %) Laminations resin (67%)	Bamboo (26.7 %) Fiber carbon (8.5 %) Laminations resin (64.8%)

Table 4. The mechanical properties of the material tested.

Material	Available	Suggested
Yield stress σ y (Mpa)	33.5	40
Ultimate stress σ ult (Mpa)	37	97.2
Modulus of elasticity (E) (Mpa)	1100	1980
Poisson's ratio(υ)	0.24	0.25

5.3 Fatigue properties

Fatigue failure occurs when the specimen fractures under alternative bending loading. The readings recorded by the fatigue tester represent the number of cycles until the specimens fatigued .The relationship between the stress and the number of the cycle from fatigue testing is illustrated in Figure 8, this curve gives an indication of the behavior in terms of fatigue life. These results are come by using three specimens for six levels of stress. Extraction of fatigue stress endurance limit from, for suggested material the stress endurance limit is equal to 61.5 Mpa. As for available material the stress endurance limit is equal to 18 Mpa. The stress endurance of suggested materials is higher than that of available material by 241%.

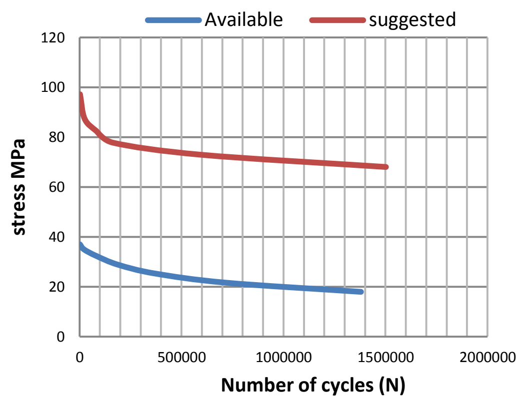

Figure 8. S-N fatigue tests curve for the available and suggested material.

5.4 Interface pressure results

After conducting tests and extracting the results of interface pressure at four regions Anterior, Lateral, Posterior, and Medial, this region was divided to three parts upper, middle and bottom. The positions and values of the pressure on the inner sides of the socket are as detailed in Table 5.

5.5 The results of analysis by (ANSYS) program

There are two cases of prosthetic socket which were analyzed by simulation program (ANSYS), first case was the available prosthetic socket material (4 perlon 2 fiber carbon 4 perlon) and second case was the suggested prosthetic socket material (1 bamboo 2 fiber carbon 1 bamboo).

ISSN 2076-2895 (Print), ISSN 2076-2909 (Online)

The equivalent Von-Mises Stresses analysis gave us knowledge on the amounts of stress and spread in the socket. The highest stress value reached was 17.9 Mpa in the socket made from available material as shown in Figure 9 and for the socket made from the suggested material was 17.6 Mpa as shown in Figure 10.
The deformation analysis gave us knowledge on the amounts of total deformation and the location in the socket that reached the highest deformation value of 10 mm in the socket made from available material as shown in Figure 11 and for the socket made from the suggested material it was 5.5 mm as shown in Figure 12.
The minimum equivalent stress-safety factor for the available prosthetic socket is equal to 0.998 as shown in Figure 13 and for the suggested prosthetic socket were 3.85 as shown in Figure 14.

Table 5. Values of interface pressure on locations selected of the prosthetic socket.

Socket regions	Sensor positions	Interface pressure KPa
Anterior	A U	128
	A M	116
	A B	106
Lateral	L U	25
	L M	50
	L B	64
Posterior	P U	125
	P M	51
	P B	80
Medial	M U	92
	M M	54
	M B	77.5

6. Conclusions
1. The physical properties: The increase in mass per unit area was 8.3% and the decrease by 3.2% in the proportion of lamination resin when comparing the suggested with available material
2. The mechanical properties: The increase in values of yield stress, ultimate stress and modulus of elasticity by 20.1%, 162.7% and 80 % respectively comparison with available material
3. Characteristics of fatigue life: for the suggested material has increase in the stress endurance was 241% compared with available material.
4. The safety factor of sockets in (ANSYS): The minimum safety factor in suggested material was increased compared with available material from 0.998 to 3.85.

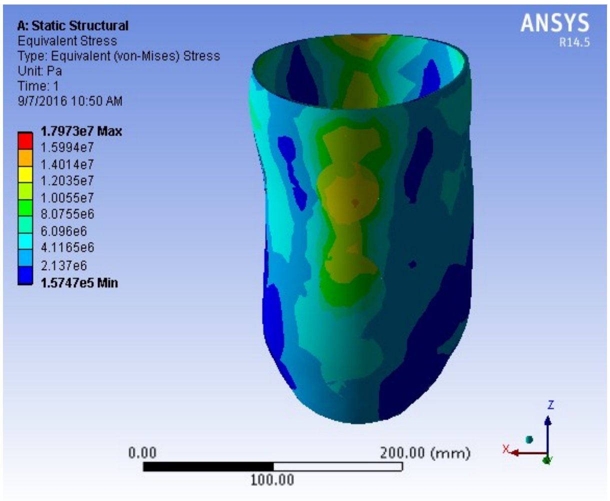

Figure 9. Von-Mises stress of available prosthetic socket material.

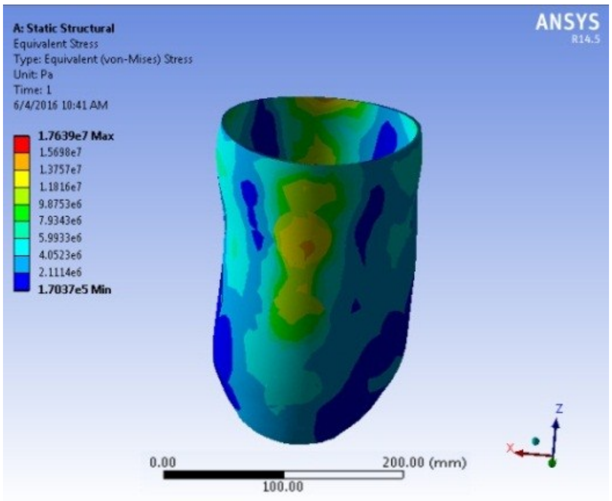

Figure 10. Von-Mises stress of suggested prosthetic socket material.

ISSN 2076-2895 (Print), ISSN 2076-2909 (Online)

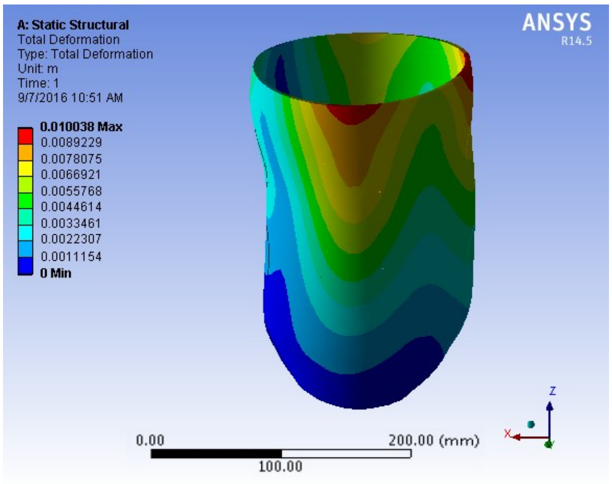

Figure 11. Total deformation for available prosthetic socket material.

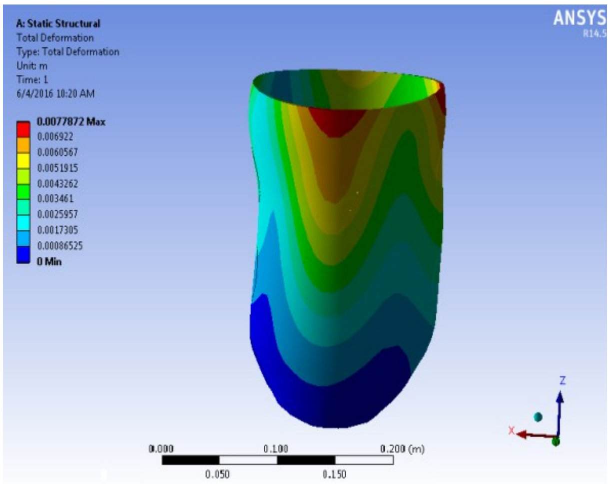

Figure 12. Total deformation for suggested prosthetic socket material.

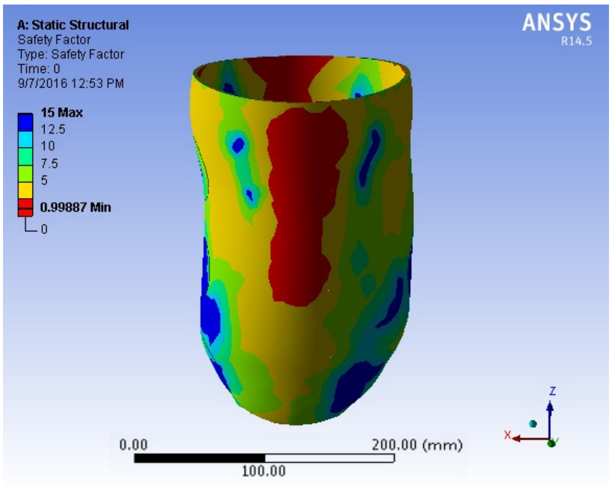

Figure 13. The equivalent stress-safety factor for available material.

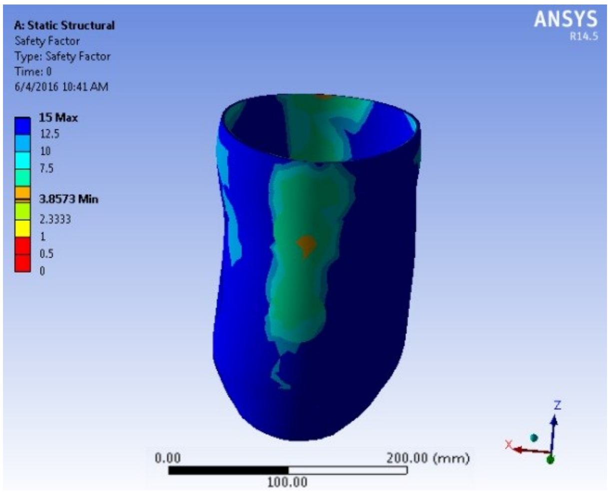

Figure 14. The equivalent stress-safety factor for suggested material.

References

[1] Douglas Murphy "Fundamentals of amputation care and prosthetics" 2th Ed Demos Medical, 2014.

[2] M.J.jweeg, S.S.Hasan, and J.S.Chiad "Effects of Lamination Layers on the Mechanical Properties for Above Knee Prosthetic Socket" Eng.&Tech.Journal,Vol.27,No.4,2009.

[3] S. J. Jana, Mohsin J. Jweeg "Vibration Analysis of Prosthesis for the through knee Amputation", Al-Nahrain University, College of Engineering Journal (NUCEJ) 91 (1), 2016 pp.46-55.

[4] Shireen Hasan Challoob, KadhimKamil Resan, and Yasir Khalil Ibrahim "Stress Relaxation on Prosthetic Laminated Socket Materials ", Journal of Engineering and Development, Al-Mustansiriyah University, 2015, 19 (3), Pages: 110-124.

[5] M.J. Ibrahim, " Hygrothermal Effect on Dynamic Loading of laminated lower limb Socket and Bacteria Growth", MSc. Thesis, Al-Mustansiriyah University, Dept. of Mech. Engineering, 2015.

[6] Polona Dobnik Dubrovski "Woven Fabric Engineering" First published November 2010.

[7] Živa Zupin and Krste Dimitrovski "Mechanical Properties of Fabrics from Cotton and Biodegradable Yarns Bamboo, SPF, PLA in Weft" University of Ljubljana, Faculty of Natural Sciences and Engineering, Department of Textiles Slovenia, 2010.

[8] American Society for Testing and Materials International "Standard Test Method for Tensile Properties of Plastics" D 638, 2000.

[9] Alternating Bending Fatigue Machine instruction manual HSM20.

[10] Akeel Zeki Mahdi, "Design and Analysis of Knee Ankle Foot Orthosis", Thesis, Department of Mechanical Engineering University of Technology 2012.